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Modern strategies in burn wound management: A review of therapeutic approaches and future perspectives

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ABSTRACT

Burn wounds represent a severe health issue, requiring numerous hospitalizations in Poland. Local treatment of burns includes special dressings (e.g., fatty gauze, hydrocolloid, hydrogel, alginate) and surgical methods. Biosynthetic skin substitutes and antiseptics like silver sulfadiazine can also be used. Surgical procedures include tangential excision of necrotic tissue, fascial excision, and skin grafts (autografts, allografts, xenografts). These techniques are essential in partial and full-thickness deep burns treatment. Surgical intervention reduces the risk of wound infection by closing possible portals for the pathogens that cause sepsis. The aim of the paper is to overview the various treatment methods of burn wounds, according to the depth of the lesion and the impact on the healing process.

Keywords: Burns, dressings, skin graft, surgical treatment methods, sepsis

1. INTRODUCTION

There are several mechanisms that can cause burn wounds, such as heat, radiation, and friction. In most cases, the primary cause of these injuries is contact with hot liquids or direct exposure to fire. Undoubtedly, burn care represents a significant challenge for the healthcare systems worldwide (Jeschke et al., 2020). The statistics show that in 2022, 516 cases of moderate burns/frostbites, 159 cases of severe burns, and 810 cases of severe burns requiring surgical intervention were recorded in the adult population in Poland. Additionally, there were 5 cases of extreme burns and 49 cases of extreme burns with surgical intervention. In the pediatric population, 26 cases of severe burns were reported, along with 277 severe burns requiring surgery, 274 moderate burns/frostbites, and 585 moderate burns/frostbites with surgical intervention (NFZ Statistics Map).

Only 30% of patients requiring hospitalization receive specialized medical care in burn centers. The remaining patients are admitted to general surgery wards. Each patient requires an individualized approach and a tailored treatment plan (Strużyna, 2022). We can find records in the Egyptian Smith Papyrus, dating back around 1600 BCE, about the use of honey and resin in the treatment of burn wounds. The mention of using various medicinal substances to treat burn wounds can be found in the Ebers Papyrus, dating to approximately 1500 BCE. In China, around 600 BCE, the use of tea leaf extracts and tinctures for burn treatment was described (Lee et al., 2014). New treatment methods for burn wounds, leveraging the latest medical knowledge and molecular biology, have improved patient outcomes, especially in clinically challenging cases, which led to better therapeutic results, positively impacting survival rates and patients' post-treatment quality of life.

Objective

The aim of this study was to present available and currently used methods for treating burn wounds according to their severity and to evaluate the impact of these methods on the healing process of burn wounds.

2. MATERIALS AND METHODS

The methods utilized in this article consist of a literature review. We have conducted a detailed analysis of clinical studies, meta-analyses and systematic reviews, with the main focus on the latest techniques and therapeutic approaches. Traditional treatment methods as well as modern technologies, such as cell therapies, tissue engineering, and innovative dressing materials, were taken into account. The literature review included specialized textbooks and publications from the PubMed database, utilizing keywords in two languages (Polish/English): oparzenia/burns, opatrunki/dressings, przeszczep skóry/skin draft, chirurgiczne metody leczenia/surgical treatment methods, sepsa/sepsis.

3. RESULTS AND DISCUSSION

Epidemiology

Each year, over 300,000 people worldwide lose their lives due to burns caused by fires. Electrical burns, chemical burns, and other types of burns contribute to an even higher number of deaths.

Pathophysiology

Thermal burns result in localized skin damage, categorized into three zones. The innermost zone is surrounded by the area of ischemia or stasis with an increased risk of conversion to necrosis due to insufficient blood supply or infection. In other words, it is the area of coagulation or necrosis, where irreversible cell death occurs. The outermost zone is the area of hyperemia, associated with the reversible dilation of blood vessels (Schaefer and Tannan, 2023). It is important to mention that burn injuries can trigger a systemic response in addition to causing local damage. In cases of extensive burns (>20% of body surface area), large amounts of vasoactive substances and inflammatory mediators are released, leading to systemic capillary leakage, loss of intravascular fluid, and significant fluid shifts (Arbuthnot and Garcia, 2019). Shortly after the burn, we can observe a reduction in the Relative Vascular Area (RVA).

Additionally, the oxidative stress response in tissues may be linked to increased activity of oxidative stress enzymes such as GPX1, SOD1, and Nqo1 within the wound. It serves to counterbalance the reactive oxidants typically released during inflammation. The early inflammatory response leads to infiltration by innate immune cells. Quantitative assessment of leukocyte infiltration, measured through the activity of myeloperoxidase (MPO) in the central part of the wound, peaks early and then decreases to low levels within 24 hours. At the wound edges, the MPO peak declines after about 48 hours, suggesting a smaller area of thrombosis than the center. Hypothetical, leukocytes trapped in the damaged tissue are the primary source of pro-inflammatory mediators, leading to microcirculatory damage (Bohr et al., 2013).

Assessment of Burn Depth and Extent

According to the classification adopted by the American Burn Association, burns can be categorized based on their depth and extent. The depth of a burn has a decisive impact on the clinical course of the disease in burn patients. The structural and anatomical classification into four categories of increasing burn depth is mainly theoretical, as surgeons prefer a more clinical approach. This

approach distinguishes between superficial wounds that heal with conservative treatment and deep wounds that require surgical intervention (Wearn et al., 2018). Since the 16th century, visual assessment of burn depth has been indispensable.

Although it is still the most commonly used method, recent research has been conducted on new technologies to evaluate burn injuries. Findings indicate the potential for early burn classification using Laser Doppler Imaging (LDI). This method is gaining increasing acceptance as a tool to assist in the assessing burn depth. Despite its longer duration, Doppler imaging has higher diagnostic accuracy than LDI with thermography, likely due to the influence of environmental factors on thermographic imaging (Wearn et al., 2018). The extent of a burn refers to the total area of skin affected by the burn. Along with burn depth, it is a crucial determinant of burn severity.

To describe the extent of burns, the percentage of total body surface area (%TBSA) is used. Wallace's rule of nines is a simple method for estimating the percentage of burned surface area. The palm surface area represents 1% of TBSA, while larger body areas are assigned 9% TBSA or its multiples. A more accurate method of assessing burn extent is the Lund-Browder chart, which shows the percentage of each body part relative to the patient's age. However, it is essential to note that knowing only the %TBSA without knowing the burn depth has limited prognostic and predictive value (Strużyna, 2022).

Local Treatment

There are currently many methods for managing damaged skin. It is important to select the appropriate treatment method, as it significantly impacts the appearance of scars in the long term. There are a few available options, including antiseptic agents, specialized dressings, and surgical treatments. The new insights into wound healing have broadened the range of burn treatment options available today compared to previous years (Wasiak and Cleland, 2015). There are numerous specialized dressings on the market.

Proper treatment of the injury is crucial to achieving therapeutic success. Still, to date, there is no perfect burn wound dressing created or widely implemented that ensures complete, independent healing without constant supervision or dressing changes. Most of these dressings are beneficial for treating various types of burn wounds (Markiewicz-Gospodarek et al., 2022). Creating the appropriate conditions for skin regeneration is vital to the patient's prognosis and it is achieved through the proper selection of treatment methods, often involving a combination of several techniques.

Local Treatment of First-Degree Burns

First-degree burn injuries affect only the epidermis and typically undergo spontaneous healing, resulting in no scarring. Treatment primarily focuses on cooling the burn site with lukewarm water for about 30 minutes. Afterward, it is recommended to apply a hydrogel dressing to reduce the risk of deepening the thermal injury (Hettiaratchy et al., 2005).

Hydrogel Dressings

These dressings can take various forms, such as sheets or gels applied to gauze. They contain natural and synthetic polymers, with a water content of up to 90%. This type of dressing is highly biocompatible, offers controlled physical parameters, provides natural drug delivery structures, and includes various functional groups (Zhao et al., 2018). Due to the different needs for wound regeneration, there are hydrogel dressings enhanced with additional features such as excellent tissue adhesion, antibacterial properties, support for cell migration, local immune regulation, and even anticancer properties (Yang et al., 2021; Fang et al., 2019; Wang et al., 2021).

Local Treatment of Superficial Partial-Thickness Burns (IIA)

Superficial partial-thickness burns damage the entire epidermal layer and the superficial layer of the dermis. For this reason, they usually heal spontaneously within two weeks. The main therapeutic goal is to prevent complications and protect the burn wound from being infected and because of that, the most effective treatment method is to use topical antimicrobial agents and occlusive dressings such as hydrocolloid or alginate dressings (Hettiaratchy et al., 2005).

The Role of Antiseptics

Burn wound infection and sepsis are the most common complications in burn patients. The 2016 National Burn Repository report revealed that 7 out of the 10 most common complications in burn patients were infection-related, including pneumonia, urinary tract infections, and cellulitis. Sepsis remains a significant cause of death among patients with extensive burns. Of particular concern are

multidrug-resistant pathogens such as *Pseudomonas aeruginosa*, *Acinetobacter baumannii*, *Stenotrophomonas maltophilia*, and methicillin-resistant *Staphylococcus aureus* (MRSA) (Lachiewicz et al., 2017).

Silver Sulfadiazine (SSD)

SSD is a topical medication utilized to prevent and treat infections in burn wounds. As a member of the heavy metal topical agents, it exhibits potent antibacterial properties. However, recent reports indicate that it delays wound healing and although considered safe, its use should be limited. When the first signs of healing appear, SSD use should be discontinued, as it may result in the formation of pseudo-eschar in the affected area, complicating the accurate assessment of the burn wound and necessitating frequent and often painful mechanical debridement (Nímia et al., 2019; Oaks et al., 2023).

To avoid potential side effects such as allergic reactions, silver discoloration of the treated wound, or hyperosmolarity, silver-enriched dressings can be used as an alternative (Selig et al., 2012). On the market, there are some silver products available: nanocrystalline silver dressings, silver combined with activated carbon, and silver-foam dressings. Modern medicine often utilizes silver nanoparticles (AgNP) due to their unique physicochemical properties. In this form, silver retains its bioactive properties. AgNPs exhibit antibacterial, antioxidant, anticancer, and anti-inflammatory properties. The antimicrobial effectiveness of silver nanoparticles is mainly due to their ability to bind to the surface of pathogens, making them effective against both Gram-negative and Gram-positive bacteria (Rybka et al., 2022).

Arnebia euchroma

Growing in the high-altitude regions of the Himalayas**,** Arnebia Euchroma is a tremendously valuable medicinal plant having confirmed wound healing properties. It has been used to prepare an ointment (AEO) to compare its effects with silver sulfadiazine. At the Traditional and Complementary Medicine Research Center in Sari (Iran), scientists conducted a prospective, randomized, single-blind study. The study compared pain, burning sensation, warmth, erythema, swelling, infection, inflammation, and overall wound surface. It showed that healing time was shorter in the AEO-treated area than in the SSD-treated area. Additionally, the intensity of pain and burning in the AEO-treated area was lower compared to SSD (Nasiri et al., 2016). Antiseptic agents aim to prevent the growth of microorganisms, offering a broad range of actions to avoid infection and to promote burn wound healing.

Hydrocolloid Dressings

Hydrocolloid dressings are occlusive and are made from a hydrocolloid matrix combined with a vapor-permeable film or foam backing. Upon application, the matrix forms a gel that provides a moist environment promoting wound healing (Dumville et al., 2013). This environment likely accelerates healing by maintaining moisture and warmth at the wound site. Hydrocolloid dressings act as a physical barrier, protecting the wound while absorbing exudate. They help keep the wound dry and clean, preventing bacterial contamination of the surrounding area (Moore and Webster, 2018).

Alginate Dressings

Alginate Dressings consist of compounds that naturally occur in the cell walls and extracellular matrix of various species of brown algae (Jost and Sapra, 2023). They are composed of repeating units of D-mannuronic acid and L-guluronic acid (G), linked by β-1,4 bonds in varying proportions. Due to their excellent biocompatibility and liquid absorption capacity, they are widely spread in the world of biomedicine and engineering (Zhang and Zhao, 2020). Along with having great absorbing properties, the dressings create a gel that maintains a moist physiological environment. Alginates are available as hydrogels, films, foams, nanofibers, membranes, and sponges. Studies confirm the effectiveness of alginate dressings in wound healing processes (Aderibigbe and Buyana, 2018).

Hydrofiber Dressings

Hydrofiber Dressings are soft, sterile dressings composed of sodium carboxymethylcellulose. They can absorb large amounts of fluid and transform into a gel, which helps maintain appropriate wound hydration. The gelation process allows the dressing to adhere to the wound surface without sticking to newly formed tissue, minimizing the risk of damage during dressing changes. Because they protect delicate, healing tissue and reduce discomfort associated with dressing changes, these dressings are highly effective in treating second-degree burn wounds.

Some also contain silver ions (Ag), which provide antimicrobial properties. Silver ions are gradually released upon hydration, offering long-lasting antimicrobial protection against many bacteria, including resistant strains like MRSA (methicillin-resistant *Staphylococcus aureus*) and VRE (vancomycin-resistant *Enterococcus*). For this reason, they are especially recommended for burns with a high risk of infection. In summary, hydrofiber dressings with added silver accelerate burn wound healing, reduce the risk of infection, and ensure a comfortable treatment process (Wu et al., 2023; Muangman et al., 2010; Lau et al., 2016).

Topical Treatment of Deep Partial-Thickness Burns (IIB)

In such burns, the damage extends to the epidermis and deep dermis layers. Typically, these burns do not heal within three weeks. The longer the healing process is, the higher the risk of scarring. It increases from 33% to 78%. Therefore, a skin graft is recommended within the first 5–10 days post-injury, especially for areas like the face. Some second-degree burns can heal spontaneously, if the right conditions, such as moist environment and infection prevention, are ensured. During the waiting period before grafting, it is recommended to use local dressings such as hydrocolloids, alginates, or biosynthetic skin substitutes that meet the requirements mentioned above (Hettiaratchy et al., 2005).

Biosynthetic Skin Substitutes

Constructed out of inorganic molecules and polymers, are a diverse group of biological/synthetic materials allowing temporary or permanent wound closure. They can temporarily or permanently take over skin functions. The biomaterial creates an extracellular matrix that enables the infiltration of surrounding cells (Snyder et al., 2020). Substitutes should act as stable, biodegradable scaffolds that support the synthesis of new skin tissue. Additionally, they must be resistant to tensile forces and imitate skin tissue functions, allowing host or other cells to proliferate within their structure. Their structure should remain intact for at least three weeks to promote the growth of blood vessels, fibroblasts, and epithelial cell coverage (Davison-Kotler et al., 2018).

Topical Treatment of Third-Degree Burns

In third-degree burns, there is a complete loss of regenerative elements. Healing occurs only at the wound's edges and can take several weeks. Surgical intervention is necessary in this case and should be initiated as soon as possible, except for lesions smaller than 1 cm in diameter (Hettiaratchy et al., 2005). The standard treatment for partial- and full-thickness burns involves debridement of necrotic tissue and grafting, reducing the risk of infection and eliminating the transfer of toxic products into the bloodstream. Afterward, the wound is covered using autologous, allogeneic skin grafts or other skin substitutes, depending on the extent of tissue damage and the clinical condition (Strużyna, 2022).

Tangential Excision of Necrotic Tissue is a classical surgical wound debridement technique. It involves excising necrotic parts using knives until minor bleeding occurs, indicating the boundary between living and dead tissue (Strużyna, 2022). An alternative to this is hydrosurgical wound debridement, a modern cutting technology based on the force of fluid jets and the Venturi effect, which employs Bernoulli's principle. The principle states that, while molecules flowing through a narrowed tube, the fluid velocity increases and simultaneously the pressure decreases, which allows for an efficient operation. The device uses saline for creating a jet under controlled pressure, which acts as a precise hydroscalpel when released through a nozzle. It enables quick and accurate cutting of small, contoured areas.

Thanks to the Venturi effect, removed tissues are immediately vacuumed and transported to a suction collector. This method improves visibility during the procedure, prevents vaporization, and reduces the risk of inhaling contaminated particles by the device operator (Cao et al., 2023). Clinical studies comparing both methods show that scar quality after 12 months is better with hydrosurgical debridement. However, there were no significant differences in epithelial renewal time, wound infections, or graft loss between the two methods (Legemate et al., 2022). Fasciotomy, used for extensive and deep burns, involves excising necrotic tissues down to the fascia. It is associated with less blood loss and better graft acceptance, but the cosmetic outcomes remain a disadvantage (Strużyna, 2022).

Autografts require a fresh, uncontaminated burn wound for their application and are considered the gold standard for replacing damaged skin. Grafts are classified based on thickness: Split-thickness skin grafts (STSG) and full-thickness skin grafts (FTSG) (Radzikowska-Büchner et al., 2023). In addition, cultured epithelial autografts (CEA) are also available. Split-Thickness Skin Grafts (STSG) contain the epidermis and part of the dermis. The most common donor sites for autologous STSG are the lateral thigh and torso (Braza and Fahrenkopf, 2023). Compared to full-thickness grafts, STSG may be less aesthetically pleasing due to the lack of appendage

structures, leading to more frequent contractures (Prohaska and Cook, 2023). Full-Thickness Skin Grafts (FTSG) contain the epidermis and the entire dermis (Braza and Fahrenkopf, 2023). Providing proper integration within surrounding tissue, FTSG ensures healing with minimal scarring and contractures (Prohaska and Cook, 2023).

Cultured Epithelial Autografts (CEA) are sheets of autologous keratinocytes grown in a tissue culture and transferred to the burn surface (Milner, 2023). The procedure involves harvesting healthy, unburned skin from the patient in the early stages of hospitalization. The harvested tissue undergoes appropriate processing and after about three weeks the ready material is obtained (Milner, 2023; Jeschke et al., 2018). Despite the availability of CEA, it is crucial to temporarily cover the burn wound with an allograft. Moreover, a very important aspect is to understand that cultured epithelial autografts are fragile. Allografts—skin harvested from deceased donors or the amniotic membrane—are the most commonly used in burn therapy. In recent years, increased safety and availability have expanded their range of applications.

They have reduced costs and shortened hospital stays, leading to their growing use over autografts (Ahmed et al., 2023). A retrospective open clinical study comparing allo- and autografts in burn wound therapy concluded that allogeneic skin grafts are an excellent option when the burn wound is insufficiently vascularized. Compared to the use of allogeneic skin grafts as the first line of treatment, multiple autologous split-thickness skin grafts (STSG) led to more extended hospital stays among patients with similar burn severity (Kitala et al., 2016). Xenografts are clinical transplants between species. The most commonly used species for xenografts is pigs. These grafts serve as temporary dressings for burn wounds. Their drawback is the potential for immune responses leading to xenograft rejection in recipients (Sykes and Sachs, 2022).

Local Treatment of Fourth-Degree Burns

Fourth-degree burns involve full-thickness skin and the underlying tissues, such as muscles and bones. In this degree of burn, charring and necrosis of the tissues occur, necessitating surgical removal. For the healing process, it is essential to close the wound with skin grafts or, if no other methods are viable, to consider complete amputation of the burned limb (Jędrys and Chrapusta, 2015).

4. SUMMARY AND CONCLUSIONS

The treatment of burn wounds represents a significant global healthcare challenge. Over the past several years, the medical world has made spectacular progress in this area. An essential element for the proper burn wounds healing is the provision of an appropriate and moist environment by using dressings such as hydrocolloid, hydrogel, alginate or hydrofiber. Silver sulfadiazine was the gold standard for healing burn wound infections but now is replaced by specialized dressings with silver nanoparticles due to its associated adverse effects. This approach aims to enhance the efficacy of burn wound treatment by combining antibacterial, anti-inflammatory and antioxidant properties. Surgical procedures are critical in cases of partial and full-thickness burns, beginning at grade IIB. They are considered gold standards of treatment.

These procedures significantly minimize the risk of infection by debriding the wound and subsequently selecting an appropriate graft. While waiting for the graft, local dressings such as hydrocolloid, alginate, or biosynthetic skin substitutes should be used as this will prevent infection and the development of sepsis. For burn wounds on exposed areas, such as the face, the aesthetic outcome is crucial to the patient's quality of life. In grade IIIB, the treatment of choice is surgical intervention through wound debridement followed by coverage with autologous, allogenic skin grafts or other skin substitutes. In recent years, the use of allogenic grafts has increased compared to autografts due to improved safety profiles and increased availability, resulting in shorter hospitalization periods and reduced costs. In the treatment of fourth-degree burns, necrosis of deep tissues occurs, necessitating surgical excision and subsequent grafting; when this is not feasible, the affected limb should be amputated.

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Conflict of interest
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Data and materials availability
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